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(54) **OBJECT DETECTION DEVICE**

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(30) **Foreign Application Priority Data**

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G01S 7/52	(2006.01)
G01S 7/521	(2006.01)
G01S 7/526	(2006.01)

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(58) **Field of Classification Search**

CPC G01S 15/931; G01S 7/52; G01S 7/524; G01S 7/526; G01S 15/93

See application file for complete search history.

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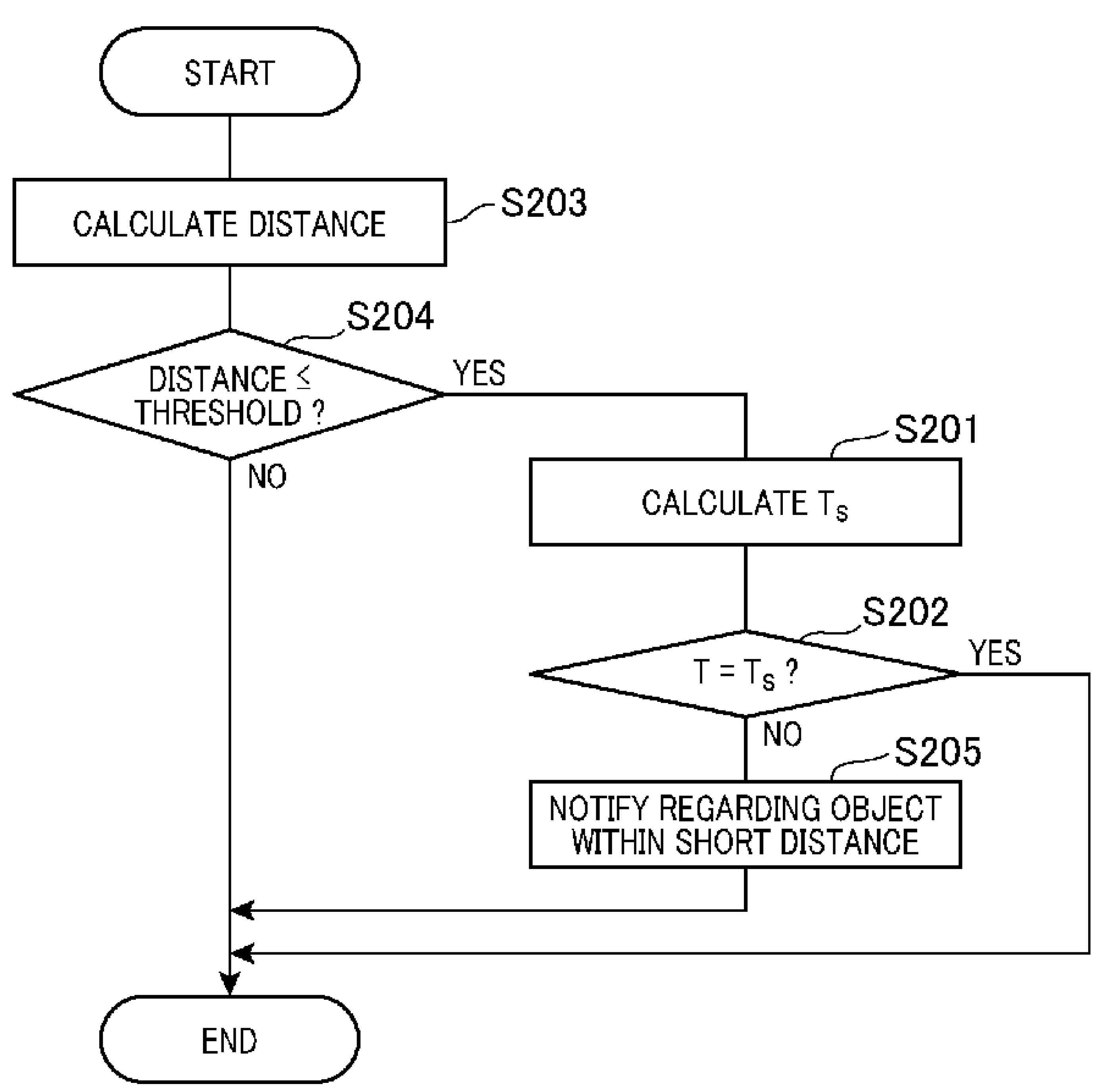
(57) **ABSTRACT**

An object detection device includes: a transceiver section that transmits an ultrasonic wave and receives an ultrasonic wave including a reflected wave of the transmitted ultrasonic wave, and outputs a signal in accordance with a wavelength of the received ultrasonic wave; a frequency control section that changes a frequency of the ultrasonic wave transmitted by the transceiver section to a plurality of frequencies different from a driving frequency used to detect the distance from the object; and a fault determination section that determines whether a fault occurs in the function of detecting the distance from the object due to a value of an environment temperature or a wavelength of the ultrasonic wave transmitted by the transceiver section, based on a value of the signal outputted from the transceiver section when the transceiver section transmits the ultrasonic wave at a selected one of the frequencies different from the driving frequency.

9 Claims, 6 Drawing Sheets



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G01S 15/87 (2006.01)

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FIG.1

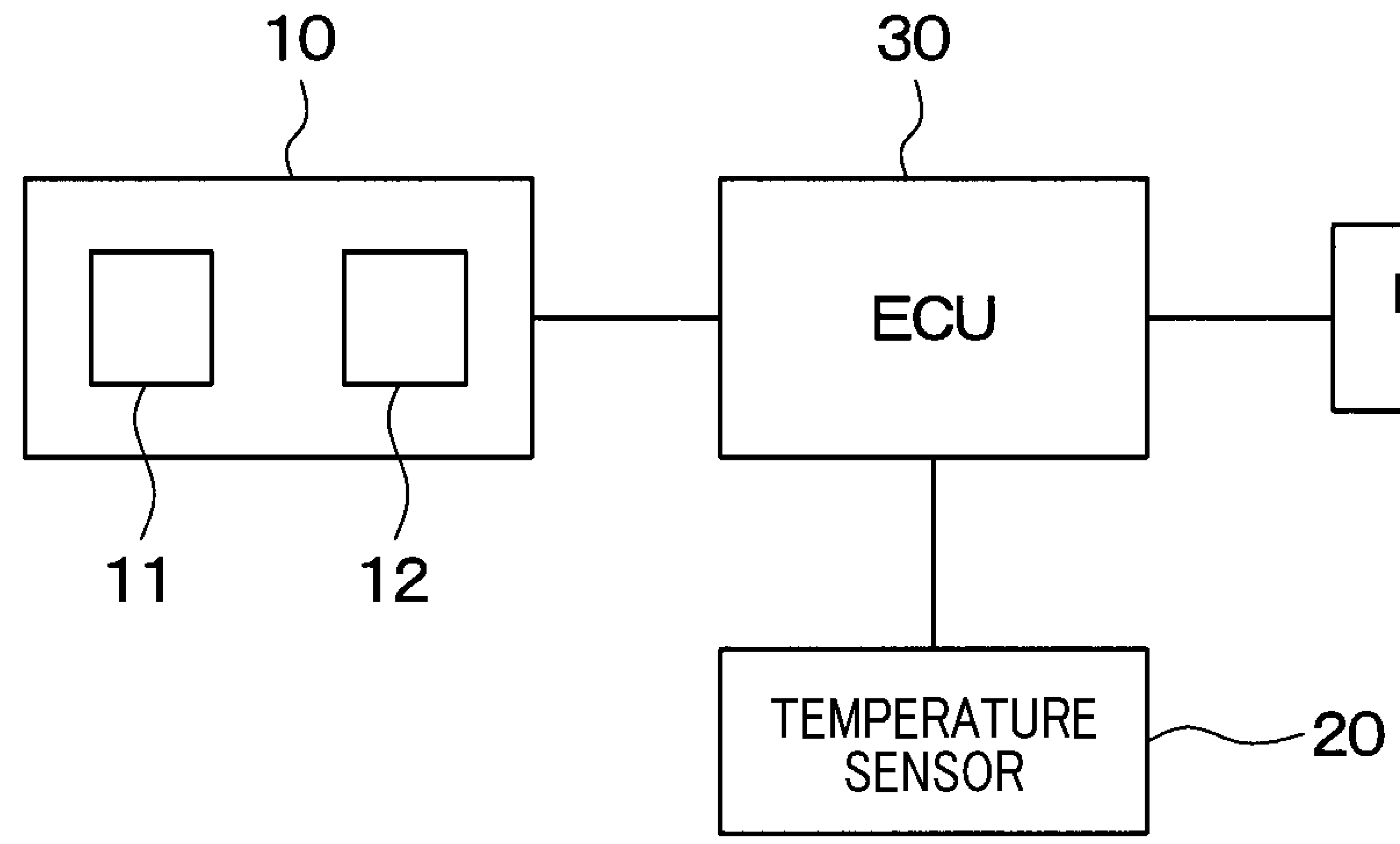


FIG.2

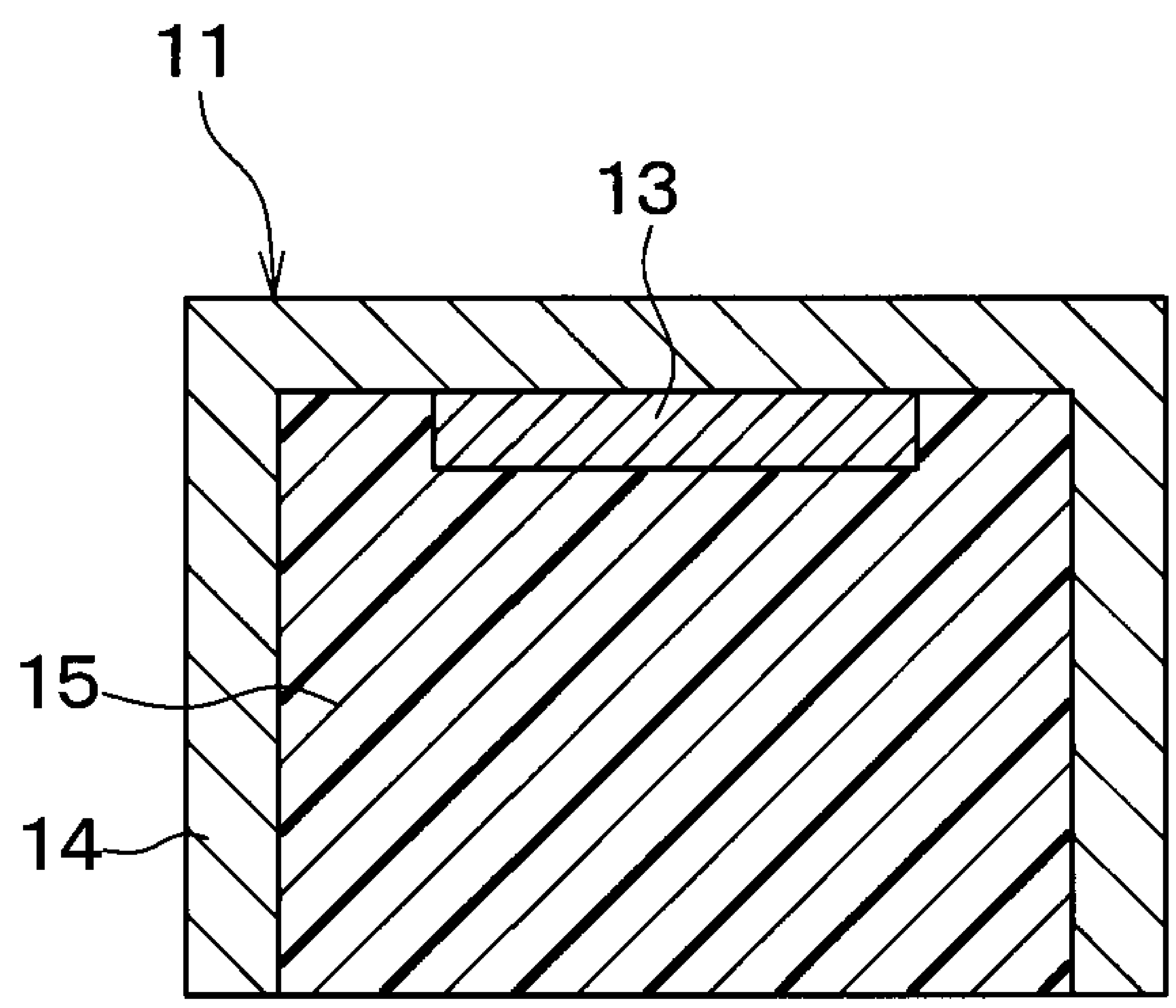


FIG.3

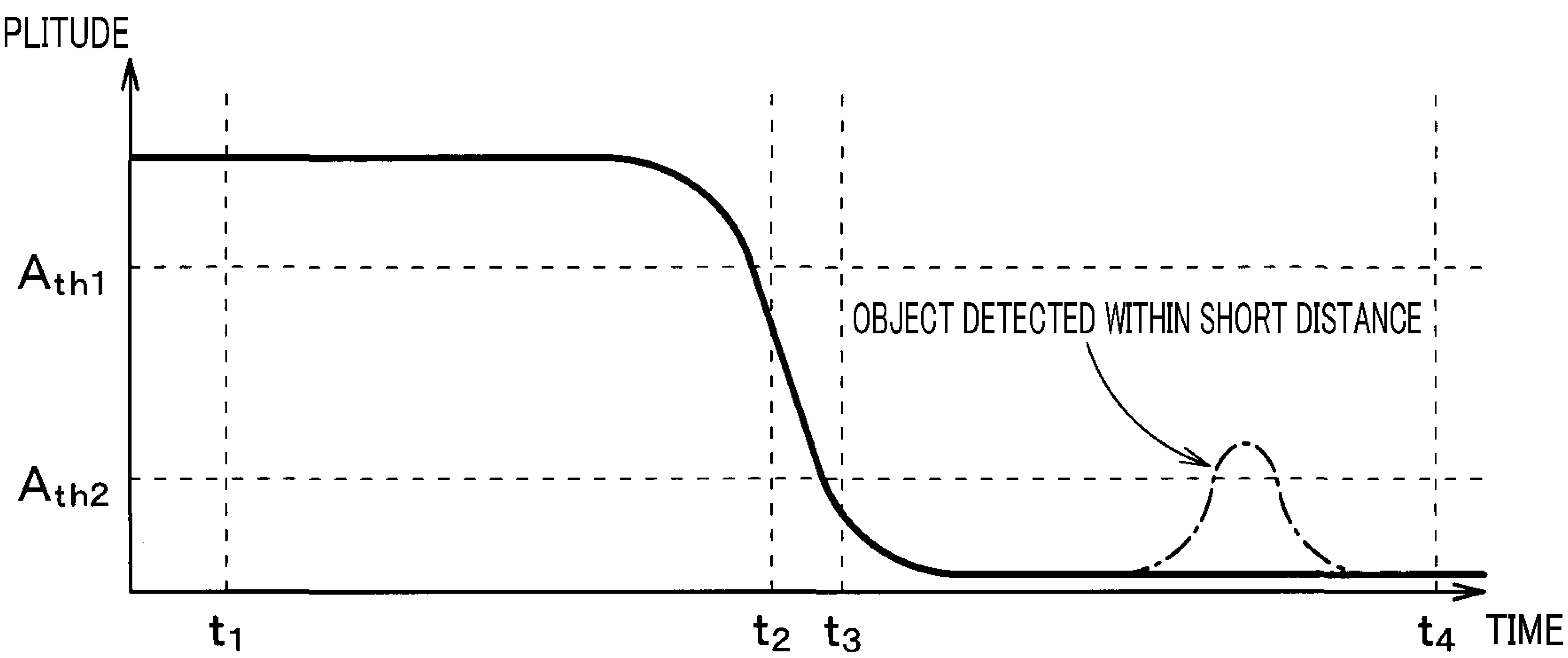


FIG.4

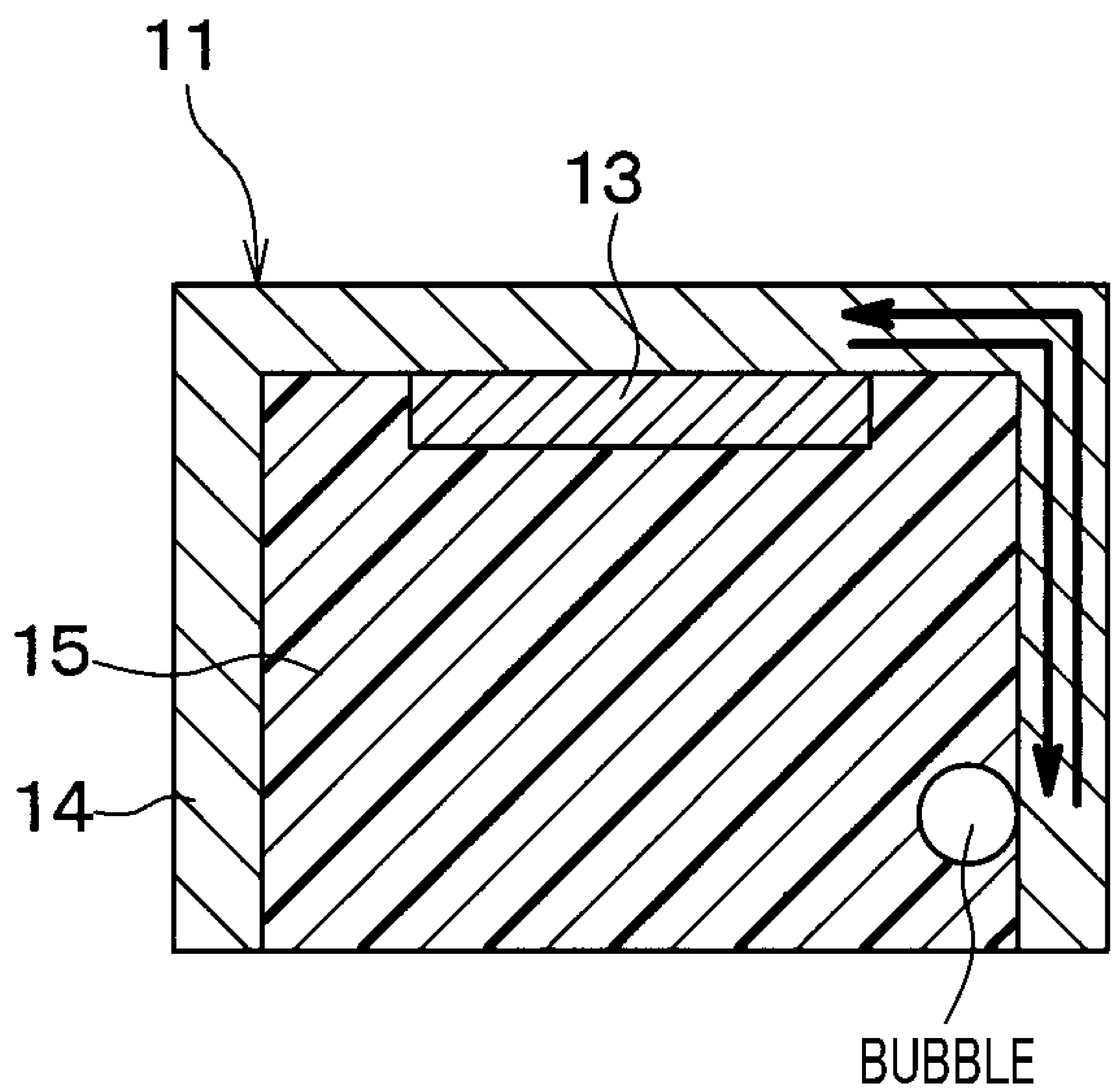

11
13
15
14
BUBBLE

FIG.5

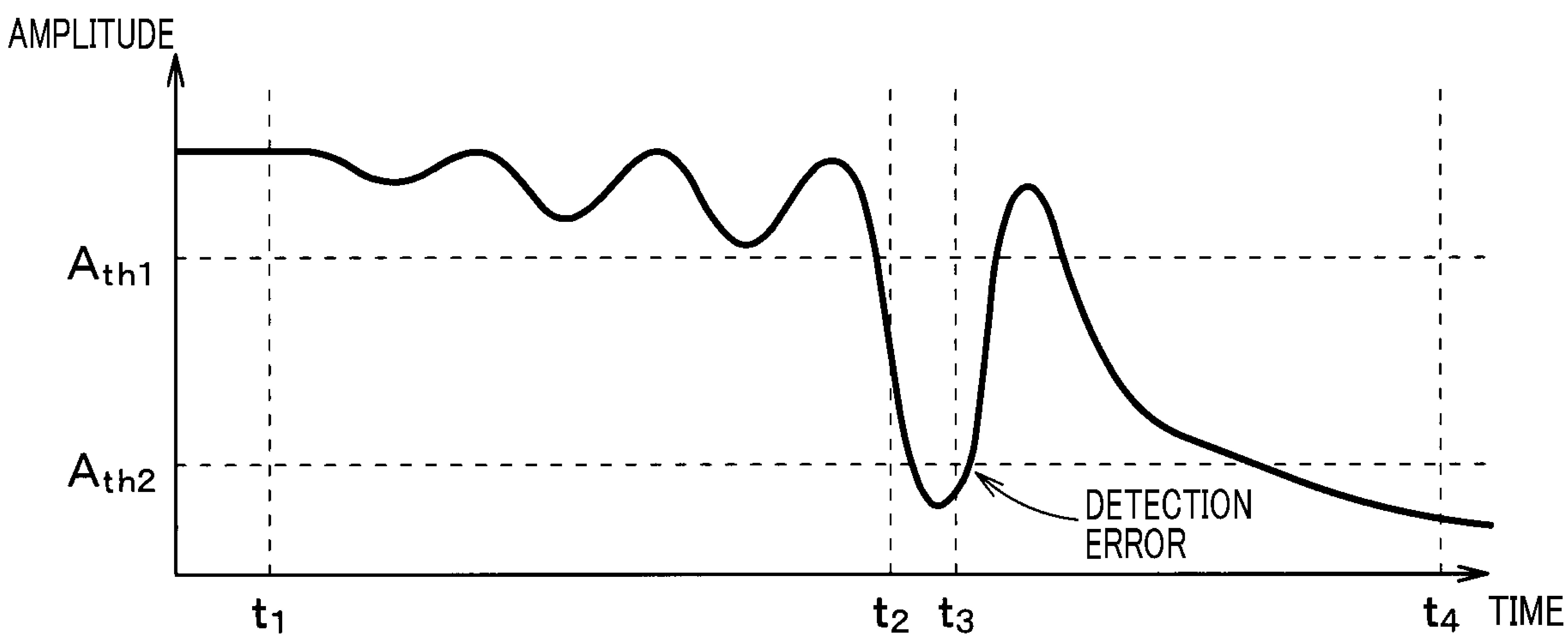

AMPLITUDE
A_{th1}
A_{th2}
DETECTION ERROR
t_1
t_2
t_3
t_4
TIME

FIG.6

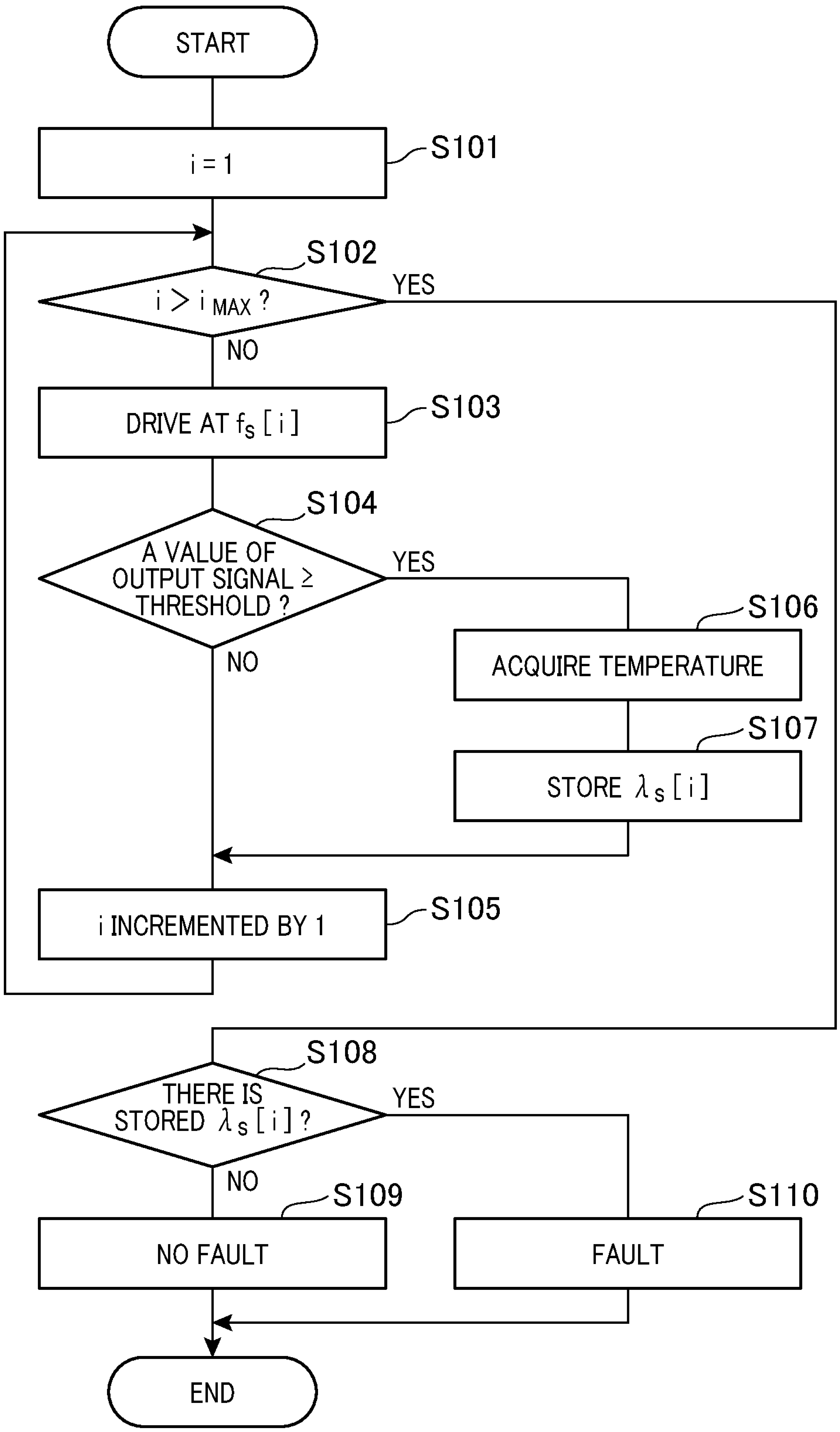

START
i = 1
S101
S102
i > i MAX ?
YES
NO
DRIVE AT fS [i]
S103
S104
A VALUE OF OUTPUT SIGNAL ≥ THRESHOLD ?
YES
NO
S106
ACQUIRE TEMPERATURE
S107
STORE λS [i]
i INCREMENTED BY 1
S105
S108
THERE IS STORED λS [i] ?
YES
NO
S109
S110
NO FAULT
FAULT
END

FIG.7

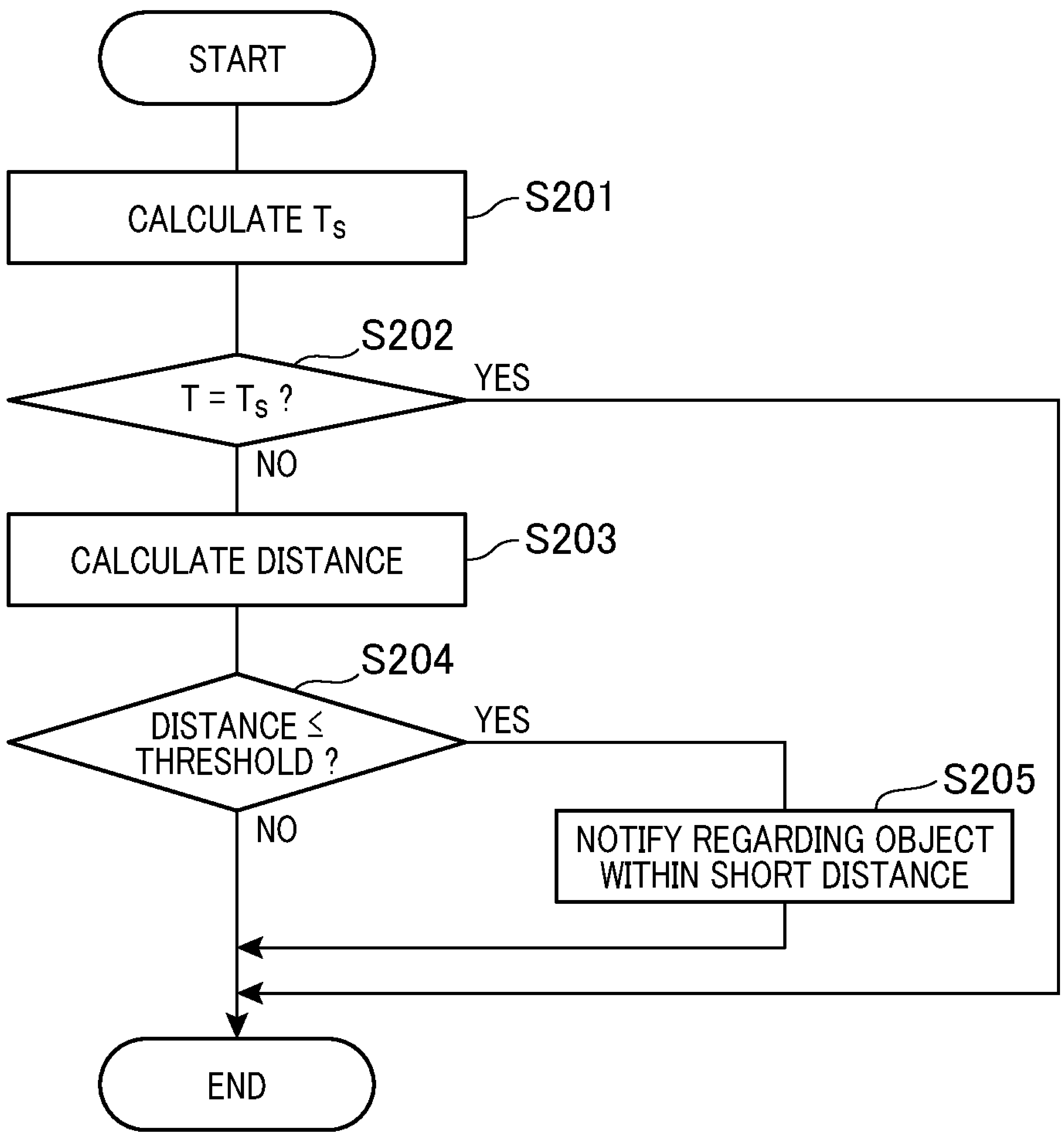

START
CALCULATE T_S
S201
S202
T = T_S ?
YES
NO
CALCULATE DISTANCE
S203
S204
DISTANCE ≤
THRESHOLD ?
YES
NO
S205
NOTIFY REGARDING OBJECT
WITHIN SHORT DISTANCE
END

FIG.8

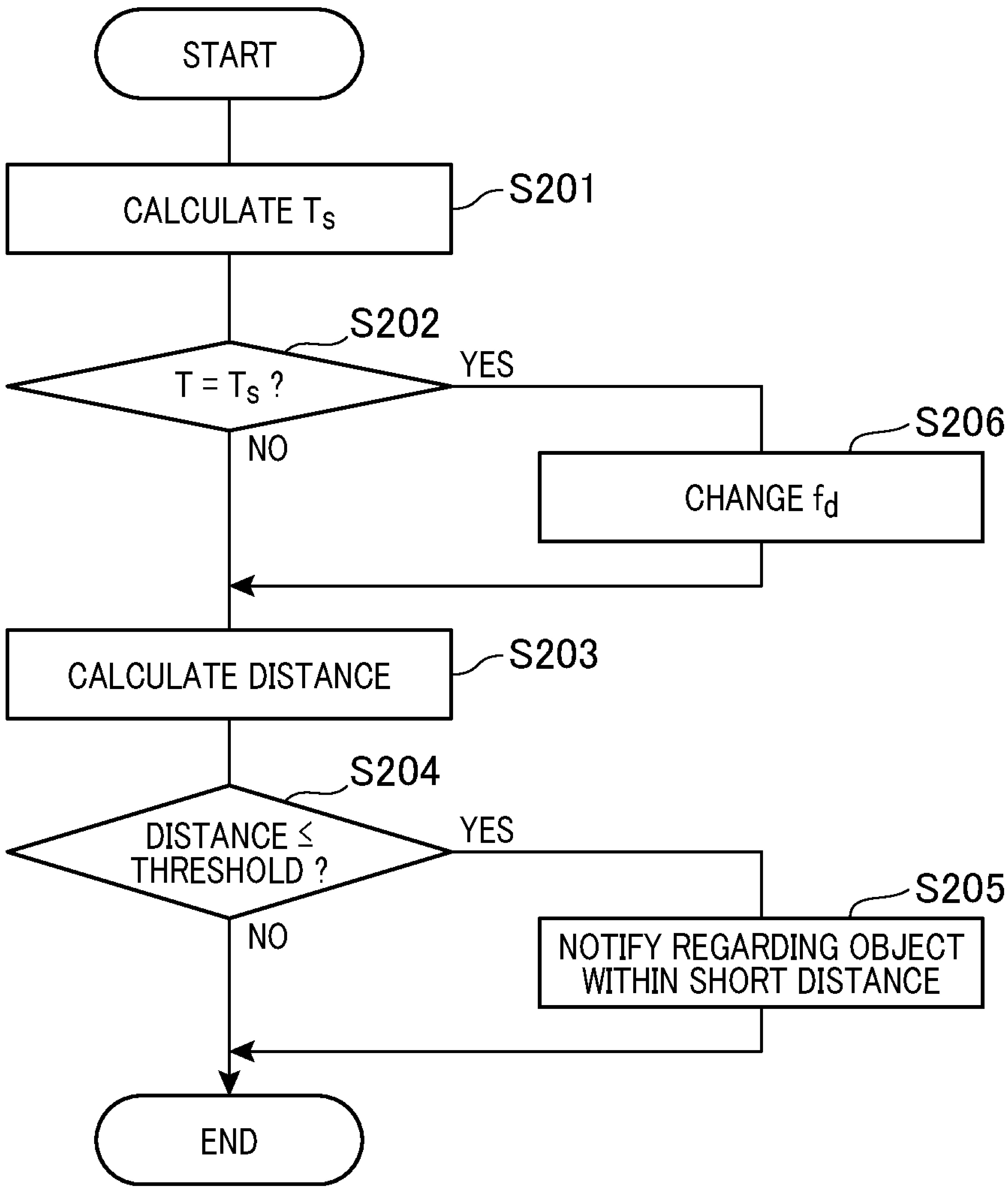
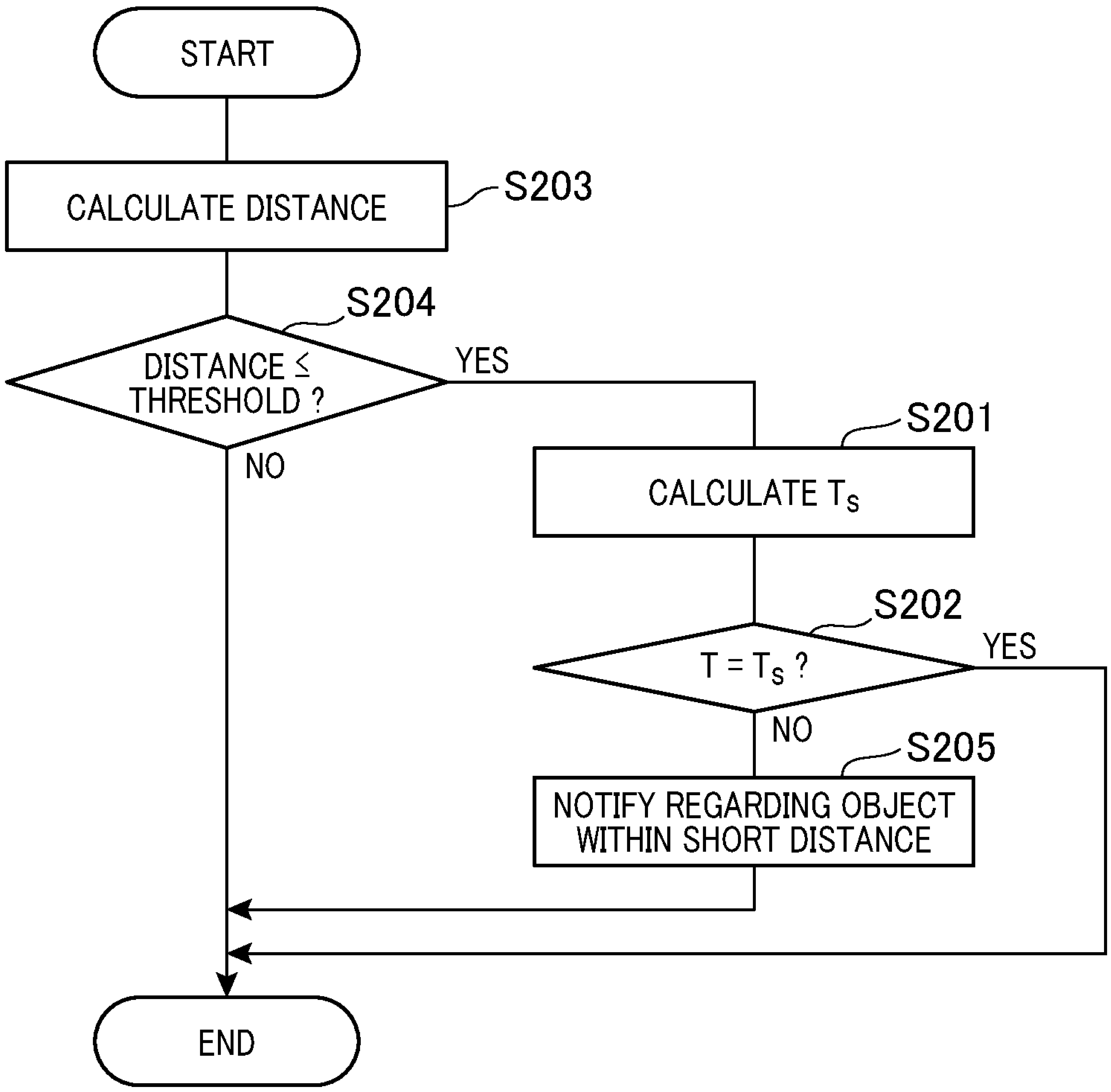

START
CALCULATE T_s
S201
S202
T = T_s ?
YES
NO
S206
CHANGE f_d
CALCULATE DISTANCE
S203
S204
DISTANCE ≤ THRESHOLD ?
YES
NO
S205
NOTIFY REGARDING OBJECT WITHIN SHORT DISTANCE
END

FIG.9


START
CALCULATE DISTANCE
S203
S204
DISTANCE ≤ THRESHOLD ?
YES
NO
S201
CALCULATE T_S
S202
$T = T_S$?
YES
NO
S205
NOTIFY REGARDING OBJECT WITHIN SHORT DISTANCE
END

OBJECT DETECTION DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

The present application is a continuation application of International Application No. PCT/JP2018/016177, filed Apr. 19, 2018, which claims priority to Japanese Patent Application No. 2017-85496, filed Apr. 24, 2017. The contents of these applications are incorporated herein by reference in their entirety.

BACKGROUND

Technical Field

The present disclosure relates to an object detection device.

Background Art

An ultrasonic sensor sends a probe wave, which is an ultrasonic wave, externally from the vehicle and receives a reception wave including a reflected wave of the probe wave and transmits a signal in accordance with the reception wave to the ECU.

SUMMARY

One aspect of the present disclosure is an object detection device provided with a function of detecting a distance from an object, the device including: a transceiver section that transmits an ultrasonic wave and receives an ultrasonic wave including a reflected wave of the transmitted ultrasonic wave, and outputs a signal in accordance with a wavelength of the received ultrasonic wave; a frequency control section that changes a frequency of the ultrasonic wave transmitted by the transceiver section to a plurality of frequencies different from a driving frequency used to detect the distance from the object; and a fault determination section that determines whether a fault occurs in the function of detecting the distance from the object due to a value of an environment temperature or a wavelength of the ultrasonic wave transmitted by the transceiver section, based on a value of the signal outputted from the transceiver section when the transceiver section transmits the ultrasonic wave at a selected one of the frequencies different from the driving frequency.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating the general configuration of an object detection device according to a first embodiment.

FIG. **2** is a cross-sectional view of a microphone in FIG. **1**.

FIG. **3** is a graph illustrating output of a normal microphone.

FIG. **4** is a cross-sectional view of a microphone in which a bubble is formed.

FIG. **5** is a graph illustrating output of the microphone in which a bubble is formed.

FIG. **6** is a flow chart illustrating a fault detection process in the first embodiment.

FIG. **7** is a flow chart illustrating an object detection process in the first embodiment.

FIG. **8** is a flow chart illustrating an object detection process in a second embodiment.

FIG. **9** is a flow chart illustrating an object detection process in another embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Conventionally, object detection devices provided with ultrasonic sensors and electronic control units (ECUs) are used for vehicles. Such an ultrasonic sensor sends a probe wave, which is an ultrasonic wave, externally from the vehicle and receives a reception wave including a reflected wave of the probe wave and transmits a signal in accordance with the reception wave to the ECU. The ECU then senses the approach of an obstacle from an output signal of the ultrasonic sensor to notify a driver and control brakes.

To prevent false notifications and malfunctions in such an object detection device, it is assumed that an object detection device must to be provided with a function to detect faults occurring in itself.

For example, PTL 1 proposes a method of determining whether a fault occurs in an ultrasonic sensor based on whether, when driving an oscillator at one frequency different from the resonance frequency of the oscillator, a wave receiving signal is detected within a detection gate time.

[PTL 1] JP 2013-104689 A

Examples of a cause of a fault in the object detection device include a bubble in a microphone configuring the ultrasonic sensor. Such a bubble in the microphone may cause amplification of the sound pressure of the ultrasonic waves propagating inside the microphone due to resonance and may result in a change in reverberation characteristics.

Such resonance occurs, for example, in the case that the diameter of the bubble coincides with the half wavelength of the ultrasonic wave. The wavelength of the ultrasonic wave is determined by the frequency of the ultrasonic wave and the temperature of the environment. Accordingly, even if a bubble is produced in the microphone, resonance occurs only at a specific temperature as long as the ultrasonic wave has a constant wavelength. When the frequency of the ultrasonic wave to detect a fault is defined as one specific frequency as described in PTL 1, resonance often does not occur even when a bubble is present in the microphone, resulting in low detectability of faults.

In view of the above problems, it is an object of the present disclosure to provide an object detection device with high detectability of faults.

According to the configuration of the present disclosure, the frequency control section changes the frequency of the ultrasonic wave transmitted by the transceiver section to a plurality of frequencies different from the frequency of the ultrasonic wave used to detect the distance from the object. Accordingly, the detectability of faults is high compared with the case where the frequency of the ultrasonic wave used to detect a fault is limited to one specific value.

Embodiments of the present disclosure are described below with reference to the drawings. In the respective embodiments below, parts identical or equivalent to each other are described with identical signs.

(First Embodiment)

The first embodiment is described. An object detection device in the present embodiment is an ultrasonic sonar device and is provided with a function of detecting the presence of an object around a vehicle, a distance from the object, and the like. As illustrated in FIG. **1**, the object detection device includes an ultrasonic sensor **10**, a temperature sensor **20**, an ECU **30**, and a notification section **40**.

The ultrasonic sensor **10** is arranged facing an outer surface of the vehicle and is configured to send a probe wave, which is an ultrasonic wave, toward the outside of the vehicle and receive a reception wave including a reflected wave of the probe wave, to output a signal in accordance with a waveform of the reception wave. The ultrasonic sensor **10** is equivalent to a transceiver section.

As illustrated in FIG. **1**, the ultrasonic sensor **10** includes a microphone **11** and a control section **12**. As illustrated in FIG. **2**, the microphone **11** is provided with a piezoelectric element **13**, a case **14** made of aluminum, and a silicon resin **15**.

The case **14** is configured with a cylindrical frame. The piezoelectric element **13** is arranged inside the case **14**, and the piezoelectric element **13** is adhered to an axial end of the case **14**. A space inside the case **14** is filled with the silicone resin **15**, and the piezoelectric element **13** is covered with the silicone resin **15**.

Wiring, not shown, is formed inside the case **14**, and via the wiring, the piezoelectric element **13** is connected to the control section **12**. An alternating voltage is applied from the control section **12** to two electrodes provided in the piezoelectric element **13**, causing deformation of a piezoelectric film and transmission of ultrasonic waves. The control section **12** receives a potential difference caused between the two electrodes when the piezoelectric film is deformed due to the received ultrasonic waves.

The control section **12** is connected to the piezoelectric element **13** and the ECU **30** and changes the frequency of the alternating voltage to be applied to the piezoelectric element **13** based on a signal from the ECU **30**. The control section **12** sends a signal, to the ECU **30**, in accordance with the potential difference between the two electrodes provided in the piezoelectric element **13**. Specifically, in the control section **12**, a band pass filter (BPF), not shown, is arranged to pass a signal in a predetermined frequency band and interrupt signals in other frequency bands different from the predetermined frequency band. The BPF has a center frequency varying in accordance with a driving frequency f_d described later. The signal outputted by the piezoelectric element **13** is processed by the BPF provided in the control section **12** and then is inputted to the ECU **30**. In the present embodiment, as described later, the driving frequency f_d is assumed to be 60 kHz and the center frequency of the BPF is assumed to be 60 kHz, i.e. the same as the driving frequency f_d.

The temperature sensor **20** detects the temperature of the environment where the ultrasonic sensor **10** is placed and outputs a signal in accordance with the temperature, and is arranged near the ultrasonic sensor **10**. The temperature sensor **20** is connected to the ECU **30** by a controller area network (CAN) communication bus or the like, and the ECU **30** performs a fault detection process and object detection process described later based on the signal outputted by the temperature sensor **20**.

The ECU **30** is configured with a known microcomputer provided with a CPU, a ROM, a RAM, an I/O unit, and the like, and executes process, such as various arithmetic processing, in accordance with a program stored in the ROM and the like. The ROM and the RAM are non-transitory tangible storage media.

The notification section **40** notifies a driver of the presence of an object at a short distance and the like in accordance with the signal from the ECU **30**. The notification section **40** is configured with, for example, a monitor, a beeper, and the like.

In the object detection device thus configured, an alternating voltage is applied from the control section **12** to the microphone **11** based on the signal transmitted from the ECU **30** to the control section **12**, causing an ultrasonic wave transmitted from the microphone **11**. The microphone **11** outputs a signal in accordance with the received ultrasonic wave, and the signal is transmitted via the control section **12** to the ECU **30**. The ECU **30** then measures a distance from the object based on time between transmission and reception of the ultrasonic wave by the microphone **11**, and based on the result of measurement, determines whether there is an object within a short distance.

Such operation is described with reference to FIG. **3**. In the graphs in FIG. **3** and FIG. **5** described later, the ordinate represents the amplitude of the output signal from the microphone **11**.

As illustrated in FIG. **3**, after the signal is transmitted from the ECU **30** to the control section **12**, when the microphone **11** sends an ultrasonic wave at time point t_1, a state where the output signal of the microphone **11** has a large amplitude continues for a while due to reverberation, but the reverberation decreases with time and the output signal amplitude decreases.

To distinguish the output signal due to reverberation from the output signal due to the reflected wave of the ultrasonic wave reflected by the object, an object at a short distance is not detected when the value of the output signal is greater than a predetermined threshold A_{th1} and until predetermined time passes after the value of the output signal becomes less than the threshold A_{th1}. Specifically, a time point when the value of the output signal becomes less than the threshold A_{th1} is defined as t_2 and a time point when a certain period of time has passed after time point t_2 is defined as t_3, and an object within a short distance is not detected between time point t_1 and time point t_3.

When there is no fault in the function of detecting the distance from the object, the output signal is attenuated even after time point t_2 and becomes smaller than a predetermined threshold A_{th2} until time point t_3. If there is no object within a short distance, the output signal continues to be attenuated until time point t_4. In contrast, if there is an object, the microphone **11** receives the ultrasonic wave reflected by the object, and as indicated by a dash dotted line in FIG. **3**, a signal having an amplitude greater than the threshold A_{th2} is outputted at a time point before time point t_4. The object within a short distance is thus detected, and the ECU **30** sends a signal indicating the presence of the object within a short distance to the notification section **40**. Time point t_4 is defined as a time point when a certain period of time has passed after time point t_1, and the time between time point t_1 and time point t_4 is set in accordance with a distance to detect an object and the like.

The object detection device thus distinguishes the output signal due to the reverberation from the output signal due to the reflected wave of the ultrasonic wave reflected by the object, by providing the threshold A_{th1} for the output signal and providing the time during which an object within a short distance is not to be detected.

However, as illustrated in FIG. **4** for example, if a bubble is formed in the microphone **11** during the process of forming the silicon resin **15**, reverberation characteristics may be changed due to resonance and a fault sometimes occurs in the function of detecting the distance from the object.

Specifically, as indicated by arrows in FIG. **4**, when the ultrasonic wave transmitted from the piezoelectric element **13** reaches a bubble through the case **14**, resonance occurs in the case where, for example, the diameter of the bubble coincides with the half wavelength of the ultrasonic wave, and the sound pressure of the ultrasonic wave is greatly amplified. The ultrasonic wave with the amplified sound pressure then returns to the piezoelectric element **13** through the case **14**, causing a large deformation of the piezoelectric element **13**.

As illustrated in FIG. **5**, the output signal due to such deformation of the piezoelectric element **13** repeats large increases and decreases of the amplitude. Accordingly, even after the state where the value of the output signal becomes less than the threshold A_{th1} continues for a predetermined period of time and passes time point t_3, the output signal sometimes becomes greater again and there is a risk of causing a detection error.

To avoid a false notification due to such a fault, the ECU **30** performs a fault detection process to detect the wavelength of the ultrasonic wave when the fault occurs. In the object detection process to transmit a signal in accordance with the distance from the object to the notification section **40**, the ECU **30** then stops transmitting of the signal to the notification section **40** when determining that the wavelength of the ultrasonic wave transmitted by the microphone **11** coincides with the wavelength of the ultrasonic wave in the occurrence of the fault.

Such fault detection process and object detection process are described with reference to the drawings. First, the fault detection process is described referring to FIG. **6**. The ECU **30** starts the fault detection process illustrated in FIG. **6** when, for example, the ignition switch of a vehicle is turned on. In addition, when the object detection process is set to be performed only while, for example, driving at less than 40 km/s, the fault detection process may be performed while driving at 40 km/s or more when the object detection process is not performed. The fault detection process illustrated in FIG. **6** may be used for inspection of the object detection device before product shipment.

As illustrated in FIG. **6**, the ECU **30** starts the fault detection process to set i=1 at step S**101** and the process proceeds to step S**102**, and the ECU **30** determines whether i is greater than a predetermined value i_{MAX} at step S**102**.

If the ECU **30** determines at step S**102** that i is not greater than i_{MAX}, the process proceeds to step S**103** and the ECU **30** drives the ultrasonic sensor **10** at a frequency $f_s[i]$. In other words, the ECU **30** transmits a signal to the control section **12** to apply an alternating voltage at the frequency $f_s[i]$ between the two electrodes of the piezoelectric element **13**.

When the driving frequency to detect the distance from the object is defined as f_d, the frequency $f_s[i]$ of the ultrasonic wave transmitted by the ultrasonic sensor **10** at step S**103** is within a predetermined frequency range including the driving frequency f_d and is defined as a frequency different from the driving frequency f_d. In addition, i_{MAX} is defined as an integer of 2 or more. In the predetermined frequency range including the driving frequency f_d, the ECU **30** changes the frequency of the ultrasonic wave transmitted by the ultrasonic sensor **10** to a plurality of frequencies different from the driving frequency f_d.

In the present embodiment, considering the range of wavelength changes due to the temperature, the range of changing the frequency of the ultrasonic wave transmitted by the ultrasonic sensor **10** is defined as ½ time or more and 3 times or less the driving frequency f_d, and the frequency $f_s[i]$ is defined to increase with an increase in i. Specifically, the range of the frequency $f_s[i]$ is defined as 30 kHz or more and 180 kHz or less. Alternatively, the frequency $f_s[i]$ may be defined to decrease with an increase in i. The ECU **30** functions as a frequency control section by executing steps S**102** and S**103**.

The ECU **30** calculates a wavelength $\lambda_s[i]$ based on an environment temperature T and the value of an output signal of the ultrasonic sensor **10** when the ultrasonic sensor **10** receives a reflected wave of an ultrasonic wave transmitted by the ultrasonic sensor **10** at the frequency $f_s[i]$. The wavelength $\lambda_s[i]$ is the wavelength of an ultrasonic wave when a fault occurs in the function of detecting the distance from the object.

Specifically, on the step proceeds from step S**103** to step S**104** and the ECU **30** acquires the output signal of the ultrasonic sensor **10**. The ECU **30** then determines whether the value of the output signal is a value in a predetermined range, and if the value of the output signal is a value out of the predetermined range, determines that a fault occurs in the function of detecting the distance from the object based on the environment temperature or the wavelength of the ultrasonic wave transmitted by the ultrasonic sensor **10**. The ECU **30** functions as a fault determination section by executing step S**104**.

In this step, the ECU **30** determines whether the value of the output signal of the microphone **11** becomes a predetermined threshold or more after a predetermined period of time has passed from application of an alternating voltage to the piezoelectric element **13**, and if the value of the output signal is a predetermined threshold or more, determines that a fault occurs in the function of detecting the distance from the object. As the threshold, for example, a threshold to distinguish the output signal due to the reverberation from the output signal due to the reflected wave of the ultrasonic wave reflected by the object, in other words, the threshold A_{th1} illustrated in FIGS. **3** and **5** may be used. The threshold may vary with the frequency $f_s[i]$.

If the ECU **30** determines that the value of the output signal of the ultrasonic sensor **10** is not the predetermined threshold or more at step S**104**, the process proceeds to step S**105** and i is incremented by 1, and then the process returns to step S**102**.

Meanwhile, if the ECU **30** determines that the value of the output signal of the ultrasonic sensor **10** is the predetermined threshold or more at step S**104**, the process proceeds to step S**106** and the environment temperature T is acquired based on the signal from the temperature sensor **20** and then the process proceeds to step S**107**.

At step S**107**, the ECU **30** calculates a wavelength $\lambda_s[i]$ (m) based on the frequency $f_s[i]$ (Hz) and the environment temperature T (° C.) acquired at step S**106**. Specifically, where the velocity of sound is defined as v(m/s), $\lambda_s[i]=v/f_s[i]$ and $v=0.6T+331.5$ and thus $\lambda_s[i]=(0.6T+331.5)/f_s[i]$. Then, the fault occurring in the function of detecting the distance from the object at the wavelength $\lambda_s[i]$ is stored and the process proceeds to step S**105**.

If it is determined that i is greater than i_{MAX} at step S**102**, the process proceeds to step S**108**, and the ECU **30** determines whether there is any wavelength $\lambda_s[i]$ stored as the wavelength at which the fault occurs.

If it is determined that there is no wavelength $\lambda_s[i]$ stored as the wavelength at which the fault occurs at step S**108**, the process proceeds to step S**109**, and the ECU **30** determines that there is no fault occurred in the function of detecting the distance from the object and terminates the fault detection process.

In contrast, if it is determined that there is a wavelength $\lambda_s[i]$ stored as the wavelength at which the fault occurs at step S**108**, the process proceeds to step S**110**, and the ECU

30 determines that there is a fault occurred in the function of detecting the distance from the object and terminates the fault detection process.

Referring to FIG. 7, the object detection process will now be described. As illustrated in FIG. 7, when the ECU 30 starts the object detection process, the ECU 30 calculates a temperature $T_s[i]$ at which a fault occurs while an alternating voltage at the frequency f_d is applied to the piezoelectric element 13, based on the wavelength $\lambda_s[i]$ at step S201. Specifically, on the basis of $\lambda_s[i]=(0.6T_s[i]+331.5)/f_d$, the temperature $T_s[i]$ is calculated for all $\lambda_s[i]$ stored as the wavelengths at which the fault occurs.

At step S202, the ECU 30 then acquires the environment temperature T based on the output signal of the temperature sensor 20 and determines whether any of the temperatures $T_s[i]$ calculated at step S201 coincides with the environment temperature T. If it is determined that any of the temperatures $T_s[i]$ coincides with the environment temperature T at step S202, the ECU 30 terminates the object detection process.

In contrast, if it is determined that no temperatures $T_s[i]$ coincide with the environment temperature T at step S202, in other words, no fault occurs in the function of detecting the distance from the object, the process proceeds to step S203 and the ECU 30 calculates the distance from the object.

Specifically, the ECU 30 transmits a signal to the control section 12 to cause the microphone 11 to transmit an ultrasonic wave at the frequency f_d and acquires a signal based on the waveform of the ultrasonic wave received by the microphone 11 from the control section 12. The ECU 30 then calculates the distance from the object, based on the time between transmission and reception of the ultrasonic wave by the microphone 11, specifically, the time from transmitting a signal to the control section 12 until inputting the output signal of the microphone 11 by the reflected wave via the control section 12.

The process proceeds from step S203 to step S204, where the ECU 30 determines whether the distance calculated at step S203 is a predetermined threshold or less. The ECU 30 functions as a distance determination section by executing step S204.

If it is determined that the distance from the object is not the predetermined threshold or less at step S204, the ECU 30 terminates the object detection process. If it is determined that the distance from the object is the predetermined threshold or less, the process proceeds to step S205.

At step S205, the ECU 30 transmits a signal indicating that the distance from the object is the predetermined threshold or less to the notification section 40 to terminates the object detection process.

In such a manner, in the fault detection process, the ECU 30 calculates and stores the wavelength $\lambda_s[i]$ at which the fault occurs, based on the environment temperature T and the output of the microphone 11 when a reflected wave of an ultrasonic wave transmitted at the frequency $f_s[i]$ by the microphone 11 is received. In the object detection process, if there is an object within a short distance, the ECU 30 then outputs a signal indicating the presence of the object within a short distance to the notification section 40. If $T=T_s[i]$ in other words, $\lambda_d=\lambda_s[i]$, the ECU 30 stops outputting the signal indicating the presence of the object within a short distance. It should be noted that λ_d is a wavelength of the probe wave transmitted by the microphone 11, and $\lambda_d=(0.6T+331.5)/f_d$.

In such a manner, it is possible to reduce detection errors and false notifications due to a value of the wavelength. For example, in a situation as illustrated in FIG. 5 where abnormal reverberation occurs due to a bubble and the like and the output signal of the microphone 11 has a large amplitude after time point t_3, it is determined made that $T=T_s[i]$ at step S202. The object detection process is then terminated without transmitting a signal indicating the presence of an object within a short distance to the notification section 40.

In the present embodiment, the frequency of the ultrasonic wave to detect a fault is further changed to a plurality of values, and thus the detectability of faults is high compared with the case that the frequency to detect a fault is limited to one specific value. In such a manner, it is possible to further reduce detection errors and false notifications for an object within a short distance.

Where the wavelength of the ultrasonic wave transmitted by the microphone 11 is defined as λ and the diameter of the bubble is defined as d, the sound pressure of the ultrasonic wave is greatly amplified by the resonance particularly when $d=\lambda/2$. However, where m is defined as an integer of 3 or more and n is defined as a natural number, the sound pressure also has a possibility of being greatly amplified when $d=\lambda/m$ and $d=n\times\lambda$.

To cope with this situation, when $\lambda_d=\lambda_s[i]/n$ or $\lambda_d=n\times\lambda_s[i]$ in the object detection process, the notification of the presence of the object within a short distance may be stopped. In other words, the temperature $T_s[i]$ for $(0.6T_s[i]+331.5)/f_d=\lambda_s[i]/n$, $n\times\lambda_s[i]$ may be calculated at step S201 to stop the notification of the presence of the object within a short distance if the temperature $T_s[i]$ coincides with the environment temperature T.

(Second Embodiment)

The second embodiment is described. In the present embodiment, the process when the temperature $T_s[i]$ coincides with the environment temperature T in the first embodiment is changed. The rest remains same as the first embodiment and thus a description is given only of the differences from the first embodiment.

In the present embodiment, the ECU 30 changes the driving frequency f_d to a value different from the original value when $T=T_s[i]$, in other words, $\lambda_d=\lambda_s[i]$.

Specifically, as illustrated in FIG. 8, if it is determined that $T=T_s[i]$ at step S202, the process proceeds to step S206, and the ECU 30 changes the driving frequency f_d to a different value from the original value to establish $\lambda_d\neq\lambda_s[i]$. Occurrence of a fault in the function of detecting the distance from the object caused by the wavelength is thus suppressed. The process then proceeds from step S206 to step S203, and the ECU 30 transmits a signal to the notification section 40 in accordance with the distance from the object.

In the present embodiment where the driving frequency f_d is changed in such a manner, it is possible to perform detection and notification of an object within a short distance even at a temperature where a fault occurs at the original driving frequency f_d.

When $\lambda_d=\lambda_s[i]/n$ or $\lambda_d=n\times\lambda_s[i]$, the driving frequency f_d may be changed to a value different from the original value. In other words, the temperature $T_s[i]$ for $(0.6T_s[i]+331.5)/f_d=\lambda_s[i]/n$, $n\times\lambda_s[i]$ is calculated at step S202, and if the temperature $T_s[i]$ coincides with the environment temperature T, the driving frequency f_d may be changed to a value different from the original value.

(Other Embodiments)

It should be noted that the present disclosure is not limited to the embodiments described above and may be changed appropriately. In each embodiment above, the components in the embodiment naturally do not have to be essential unless particularly specified as essential and obviously considered as essential from the principles. In addition, in each embodiment above, when numerical values are referred to, such as the numbers, values, amounts, and ranges of the components in the embodiment and the like, they are not limited to the specific numbers unless particularly specified as essential and obviously limited to the specific numbers in principle. Also, in each embodiment above, when the shapes, positional relationships, and the like of the components and the like are described, they are not limited to those described unless particularly specified as essential and obviously limited to the specific shapes, positional relationships, and the like in principle.

For example, in the fault detection process, the diameter d of the bubble may be calculated instead of the wavelength $\lambda_s[i]$ from the environment temperature T and the frequency $f_s[i]$, and in the object detection process the temperature $T_s[i]$ may be calculated from the diameter d and the driving frequency f_d.

The present disclosure may be applied to the case that a fault occurs due to a cause other than a bubble. For example, a fault due to a value of the wavelength of an ultrasonic wave sometimes occurs, in the case such as of extraneous matter being attached to the outside of the microphone **11** and the like. In such a case, application of the present disclosure allows calculation of the wavelength at which the fault occurs.

Although a single ultrasonic sensor **10** is used as a transmission and reception section in the first embodiment, a transmission section to transmit an ultrasonic wave and a reception section to receive an ultrasonic wave may be provided separately. Although the ECU **30** is used as the frequency control section, the fault determination section, and the distance determination section in the first embodiment, the frequency control section, the fault determination section, and the distance determination section may be arranged separately. The ECU **30** may be included in the ultrasonic sensor **10**. The temperature sensor **20** may be included in the ultrasonic sensor **10**. The control section **12** may perform some of the process performed by the ECU **30** to function as the frequency control section, the fault determination section, and/or the distance determination section.

In the object detection process, as illustrated in FIG. **9**, whether a fault occurs in the function of detecting the distance from the object may be determined only if determination is made that there is an object within a short distance. In other words, steps S**203** and S**204** may be performed after starting the object detection process, and steps S**201** and S**202** may be performed if the distance from the object is the predetermined threshold or less, and step S**205** may be performed if the temperature $T_s[i]$ does not coincide with the environment temperature T and $\lambda_d \neq \lambda_s$.

What is claimed is:

1. An object detection device provided with a function of detecting a distance from an object, comprising:

a transceiver section that transmits an ultrasonic wave and receives an ultrasonic wave including a reflected wave of the transmitted ultrasonic wave, and outputs a signal in accordance with a wavelength of the received ultrasonic wave;

a frequency control section that changes a frequency of the ultrasonic wave transmitted by the transceiver section to a plurality of frequencies different from a driving frequency used to detect the distance from the object; and

a fault determination section that determines whether a fault occurs in the function of detecting the distance from the object due to an environment temperature or a wavelength of the ultrasonic wave transmitted by the transceiver section, based on a value of the signal outputted from the transceiver section when the transceiver section transmits the ultrasonic wave at a selected one of the plurality of frequencies different from the driving frequency.

2. The object detection device according to claim **1**, wherein the fault determination section determines that a fault occurs in the function of detecting the distance from the object if the value of the signal outputted from the transceiver section when the transceiver section transmits the ultrasonic wave at the selected one of the plurality of frequencies different from the driving frequency is located outside a predetermined range.

3. The object detection device according to claim **1**, wherein the fault determination section calculates an ultrasonic-wave wavelength when a fault occurs in the function of detecting the distance from the object in accordance with:

the environment temperature; and

the value of the signal outputted from the transceiver section when the transceiver section transmits the ultrasonic wave at the selected one of the plurality of frequencies different from the driving frequency.

4. The object detection device according to claim **3**, further comprising:

a distance determination section that determines whether the distance from the object is a predetermined value or less based on a time from the transceiver section transmitting the ultrasonic wave until the transceiver section receiving the reflected wave of the transmitted ultrasonic wave, wherein

the distance determination section is configured to:

output a signal indicating that the distance from the object is the predetermined value or less, if the distance from the object is the predetermined value or less, and

stop outputting of the signal indicating that the distance from the object is the predetermined value or less, if the following equation is established:

$$\lambda_d=\lambda_s/n \text{ or } \lambda_d=n\times\lambda_s$$

where:

λ_s represents the ultrasonic-wave wavelength calculated by the fault determination section;

λ_d represents an ultrasonic-wave wavelength obtained from the driving frequency and the environment temperature; and

n represents a positive integer.

5. The object detection device according to claim **4**, wherein the distance determination section determines whether the distance from the object is the predetermined value or less if the fault determination section determines that no fault occurs in the function of detecting the distance from the object.

6. The object detection device according to claim **4**, wherein the fault determination section determines whether the fault occurs in the function of detecting the distance from the object if the distance determination section determines that the distance from the object is the predetermined value or less.

7. The object detection device according to claim **3**, wherein the frequency control section changes a first value of the driving frequency to a second value different from the first value if the following equation is established:

$$\lambda_d=\lambda_s/n \text{ or } \lambda_d=n\times\lambda_s$$

where:

λ_s represents the ultrasonic-wave wavelength calculated by the fault determination section;

λ_d represents an ultrasonic-wave wavelength obtained from the driving frequency and the environment temperature; and

n represents a positive integer.

8. The object detection device according to claim **1**, wherein the frequency control section changes the frequency of the ultrasonic wave transmitted by the transceiver section to the plurality of frequencies different from the driving frequency in a range of frequencies of ½ time or more and 3 times or less the driving frequency.

9. The object detection device according to claim **1**, further comprising:

a filter configured to pass through a part of the signal outputted by the transceiver section, so that the part of the signal is inputted to the fault determination section, the part of the signal being within a predetermined frequency band, wherein

a center frequency of the frequency band varies with the driving frequency.

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